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TECHNICAL MEMORANDUM

M63-25-1

UNITED STATES ARMY

# FRANKFORD ARSENAL

MECHANICAL PROPERTIES OF WELDED  
ALUMINUM-MAGNESIUM ALLOY PLATES

by

D. CAROSIELLO

OMS Code 5026.11.84204  
DA Project 1-H-0-24401-A-110-04

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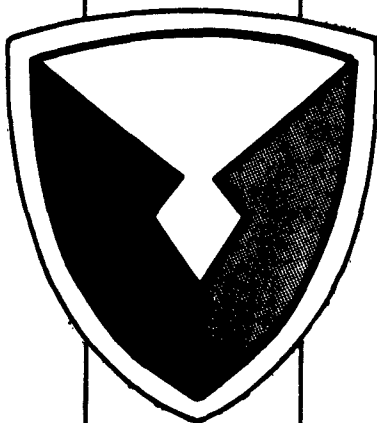
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ALUMINUM-MAGNESIUM ALLOY PLATES

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## ABSTRACT

A study was conducted to evaluate the transverse tensile properties of welds in 1-1/4 inch aluminum-magnesium alloys 5083-H115 and 5456-H321, using filler metals 4043, 5456, 5556, and 5183.

The transverse tensile properties of welds in aluminum-magnesium alloy plates of 5083-H115 and 5456-H321 were obtained for 1-1/4 inch thick plate. The filler metals tested were the aluminum-magnesium alloys 5183, 5556, and 5456, and the aluminum-silicon alloy 4043.

The test assemblies were welded by the semi-automatic gas metal-arc (MIG) welding process. The tensile specimens were tested with the weld reinforcement removed.

The highest mechanical properties for each base metal alloy were obtained using either 5183 or 5556 filler metal. The base metal/filler metal combination 5456/5556 produced the highest tensile strength of all combinations tested. The highest joint efficiency, however, was obtained with weldments 5083/5183 and 5083/5556. Although yield strengths differed only slightly among the combinations, the highest values were obtained with combinations 5456/5183 and 5456/5556. The combination 5083/5556 provided the greatest elongation within a three-inch gage length.

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## INTRODUCTION

The strain-hardenable aluminum-magnesium alloys 5083 and 5456 have been used extensively by the U. S. Army in the fabrication of light-weight airborne armored vehicles. These alloys, when compared to steel, are regarded as being highly suitable for this application because of their high strength-to-weight ratio, excellent weldability, and reasonably good resistance against ballistic impact.

The chemical composition limits of these aluminum base metals are in close proximity to one another, their main alloying element, magnesium, being in the range of 4.0 to 4.9 percent for 5083 and 4.7 to 5.5 percent for 5456.

Alloy plates of 5083 and 5456, in such tempers as H115 and H321, respectively, have been qualified for use as armor in accordance with Military Specification MIL-A-46027, "Aluminum Alloy Armor Plate, Weldable." This specification has since been amended to include higher strength requirements for unwelded test plate. This modification reflected the need for higher strength materials and was made possible by improved processing techniques of aluminum plate manufacturers.

This report, however, describes work conducted prior to the availability of these higher strength alloys. Due to the lack of comparative data, it was believed desirable to determine the mechanical properties of these alloys in the welded condition.

## MATERIALS AND EQUIPMENT

### Base Metal-Filler Metal Combinations

One and one-quarter inch thick commercial grade aluminum-magnesium alloy plates 5083-H115 and 5456-H321 were each welded with 4043, 5183, 5456, and 5556 filler metals. The results of the chemical analyses of the plates and filler metals are given in Table I.



**TABLE I. CHEMICAL ANALYSES OF ALUMINUM ALLOY  
BASE AND FILLER METALS**

	<u>Si</u>	<u>Fe</u>	<u>Cu</u>	<u>Mn</u>	<u>Mg</u>	<u>Cr</u>	<u>Zn</u>	<u>Ti</u>
<b>Base Metals</b>								
5083-H115	0.14	0.25	< 0.05	0.72	4.77	0.14	0.03	0.04
5456-H321	0.13	0.22	0.09	0.77	5.17	0.11	0.03	0.04
<b>Filler Metals</b>								
4043	5.24	$\frac{0.20}{0.50}$	0.09	< 0.01	< 0.01	< 0.01	< 0.05	< 0.02
5456	$\frac{0.05}{0.15}$	$\frac{0.10}{0.20}$	0.10	0.80	5.34	$\frac{0.10}{0.20}$	0.06	0.03
5556	< 0.1	$\frac{0.10}{0.20}$	< 0.05	0.79	5.25	0.09	ND	0.12
5183	< 0.1	$\frac{0.20}{0.40}$	< 0.01	0.60	4.79	$\frac{0.05}{0.15}$	< 0.05	0.10

ND - None Detected

The filler metals used in this investigation, with the exception of 4043 (a 5 percent silicon alloy) are aluminum alloys of the 5000 series in which magnesium is the principal alloying element. The 4043 alloy was included since it is often used as a general purpose filler material for essentially all of the weldable aluminum alloys. All of the filler wires were used as supplied on conventional spools packed in moisture proof bags.

### Shielding Gas

Commercial welding grade argon was used throughout this investigation.

### Equipment

A semi-automatic gas metal-arc (MIG) welding unit was employed. The power source was a 450 ampere dc motor generator.

## PROCEDURE

### Welding Procedure

Welded assemblies, 12 in. x 15 in. x 1-1/4 in. were fabricated from pairs of 6 in. x 15 in. x 1-1/4 in. plates. Before welding, the plates were cleaned by wire brushing and held in position by toggle clamps (Figure 1). No backup bar was used. The weld axis of each assembly was parallel to the 15-inch side and transverse to the direction of rolling of the plate. A 90° double V-joint was used with a root face of 1/16 inch and no root opening (Figure 2). The plates were welded semi-automatically using the gas metal-arc (MIG) welding process, and the following welding procedure.

Position of welding	Flat
Preheat	None
Filler metal diameter (in.)	3/32
Current (amps) DCRP	320 to 380
Voltage	25 to 27
Shielding gas	Argon
Gas flow (cu ft/hr)	60
Welding speed (in. /min)	18
Interpass temperature	Uncontrolled
Postheating	None

After the first pass was deposited, the joint was back-chipped and a second pass made on the chipped side. The joint was completed with seven passes per side, as shown in Figure 3.

### Radiographic Inspection

All weldments received complete radiographic inspection and were rated in accordance with the standards\* shown in Figure 4. The weldments used in this investigation had a "C" rating or better.

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\* Pfluger, A. R., and Kase, M. B., "The Improvement in Weld Soundness by the Use of Halogens and Halides in Inert-Gas Metal-Arc Welding of Aluminum," Kaiser Aluminum & Chemical Corp., Phase Report (Contract DA-04-200-507-ORD-333), 15 November 1955.



Figure 1. Welding Setup for welding 1-1/4 inch Aluminum-Magnesium  
5083-H115 and 5456-H321 Alloy Plates

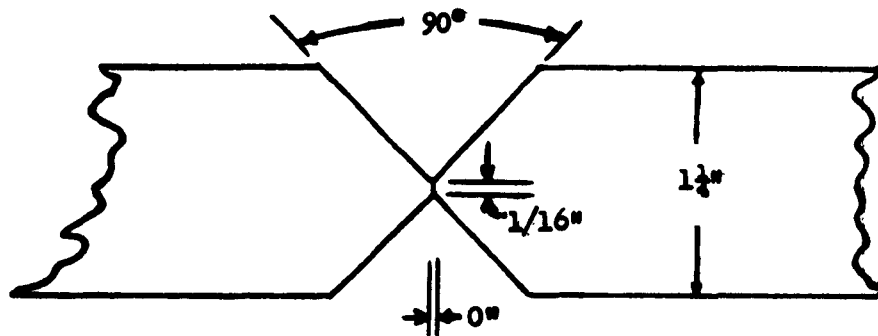


Figure 2. Joint Geometry for Welding of Aluminum Test Assemblies

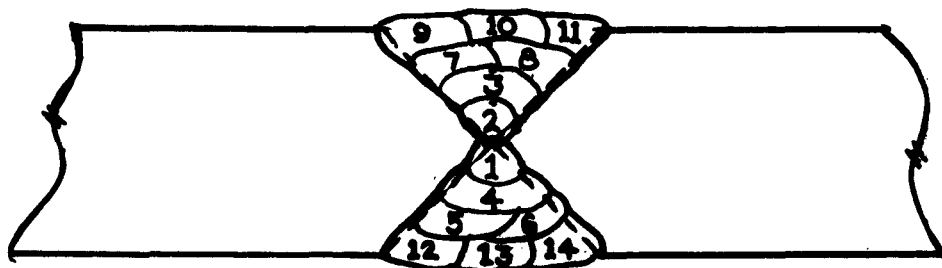


Figure 3. Pass Sequence employed in Welding Aluminum Test Assemblies

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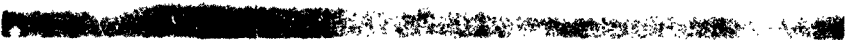
**A Rating**



**B Rating**



**C Rating**



**D Rating**

**Figure 4. Radiographic Standards for Aluminum Welds**

### Preparation of Tensile Test Specimens

Three transverse tension test specimens were removed from each weldment, Figure 5, and were machined to the size and shape shown in Figure 6. All specimens had the weld reinforcement removed. The gage length for these specimens was set at three inches in order to insure that the gage section included all of the weld and heat-affected zone.

Three tension test specimens having the same configuration as described above were also removed from each of the base metals, parallel to the direction of rolling. The testing of these specimens provided data for calculating joint efficiencies.

## RESULTS AND DISCUSSIONS

The tensile test data for the weldments are recorded in Table II together with the radiographic rating for each welded test assembly. In addition, Table II includes the location of fracture for each specimen. The average tensile results for each combination are expressed graphically in Figure 7.

The tensile strengths of all welded combinations, with the exception of those with 4043 filler, surpassed the values for corresponding annealed 5083 and 5456 base plates, as stipulated respectively in military specifications MIL-A-17358 and MIL-A-19842 (see Figure 7). The yield strengths of the weldments, however, were all greater than the specified minimum yield strengths of the annealed base plates, with very little difference between the various combinations. Although extremely low elongation values were noted with the 4043 filler metal, welds made with the aluminum-magnesium filler alloys showed good ductility within the three-inch gage length.

The ultimate tensile strengths of 5083 and 5456 weldments prepared with both 5183 and 5556 filler metals were somewhat higher than weldments fabricated with 5456 filler material. In addition, welds produced by each of these filler metals with 5456 base metal exhibited higher ultimate tensile strengths than their respective welded counterparts in 5083 base metal. This difference might be expected since it undoubtedly reflects the difference between the annealed strengths of the two unwelded base materials.

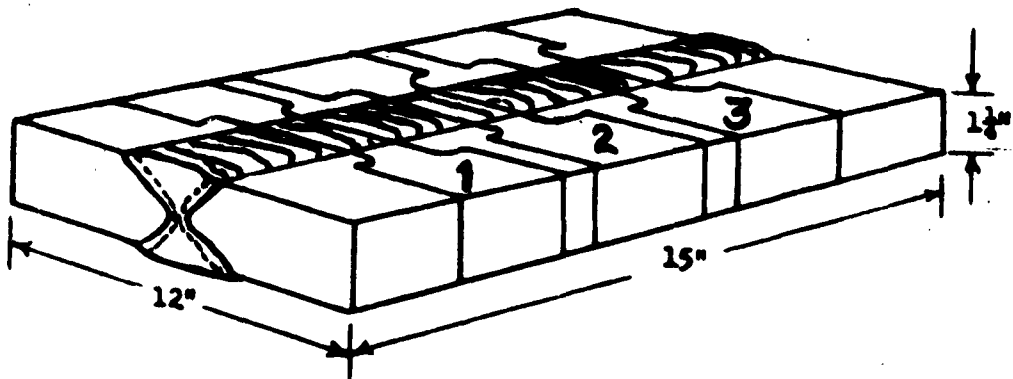


Figure 5. Test Assembly showing Location of Three Tension Test Specimens in Weldment prior to Removal

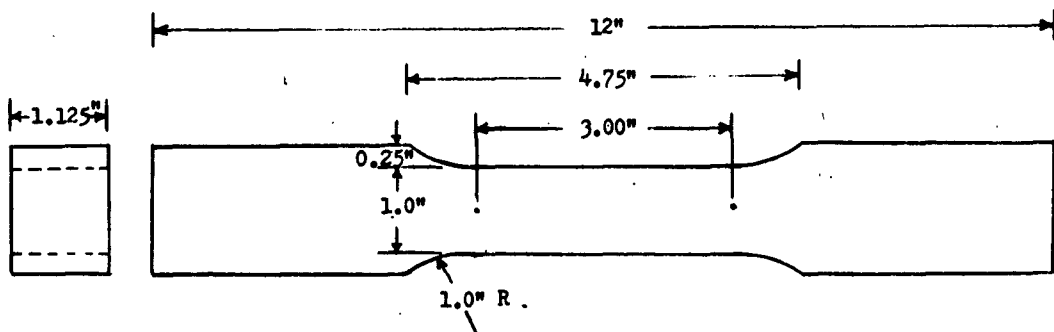


Figure 6. Sketch of Transverse Tensile Specimen

**TABLE II. Transverse Tensile Properties and Radiographic Ratings of Gas Metal-Arc (MIG) Welded Butt Joints in Aluminum Alloys 5083-H115 and 5456-H321**

Parent Alloy 1-1/4" Thick	Filler Wire 3/32"	Tensile Strength psi	Yield Strength psi	Elongation % in 3"	Joint Effi- ciency %	Location of Fracture	Radiographic Rating
5083-H115	None (Unwelded)	48,500	43,100	17.7			
"	"	46,900	41,400	18.0			
"	"	49,300	43,900	17.5			
		Avg. 48,200	Avg. 42,800	Avg. 17.7			
"	4043	29,200	22,200	2.2		WM	
"	"	29,400	22,600	2.4		"	C
"	"	29,500	22,100	2.0		"	
		Avg. 29,400	Avg. 22,300	Avg. 2.2	61		
"	5456	38,800	22,500	12.0		WM, FZ	
"	"	39,900	22,500	12.4		"	B
"	"	38,800	22,400	11.5		"	
		Avg. 39,200	Avg. 22,500	Avg. 12.0	81		
"	5556	43,800	22,800	15.3		WM, FZ, BM	
"	"	43,700	23,200	17.5		"	A-B
"	"	43,900	22,900	16.7		"	
		Avg. 43,800	Avg. 23,000	Avg. 16.5	91		
"	5183	43,800	23,500	12.4		WM, FZ, BM	
"	"	43,600	23,000	11.7		"	A-B
"	"	44,400	23,400	13.1		"	
		Avg. 43,900	Avg. 23,300	Avg. 12.4	91		
5456-H321	None (Unwelded)	54,700	32,300	21.0			
"	"	54,500	31,700	21.5			
"	"	55,200	31,400	21.6			
		Avg. 54,800	Avg. 31,800	Avg. 21.4			
"	4043	27,600	23,700	1.6		WM	
"	"	29,300	23,500	1.7		"	C
"	"	28,700	22,800	2.1		"	
		Avg. 28,500	Avg. 23,300	Avg. 1.8	52		
"	5456	45,800	23,700	11.2		WM, FZ	
"	"	45,100	23,700	11.4		"	A
"	"	41,300	23,400	9.7		"	
		Avg. 44,100	Avg. 23,600	Avg. 10.8	80		
"	5556	42,000*	25,900*	8.2*		WM, FZ, BM	
"	"	48,800	25,500	14.7		"	A-B
"	"	48,800	25,400	14.4		"	
		Avg. 48,800	Avg. 25,500	Avg. 14.6	89		
"	5183	45,800	25,500	11.0		WM, FZ, BM	
"	"	46,600	25,700	11.1		"	B
"	"	47,200	25,400	12.1		"	
		Avg. 46,500	Avg. 25,500	Avg. 11.4	86		

WM = Weld Metal  
FZ = Fusion Zone  
BM = Base Metal

\* Not included in the average due to large inclusion at fractured weld interface of test specimen.



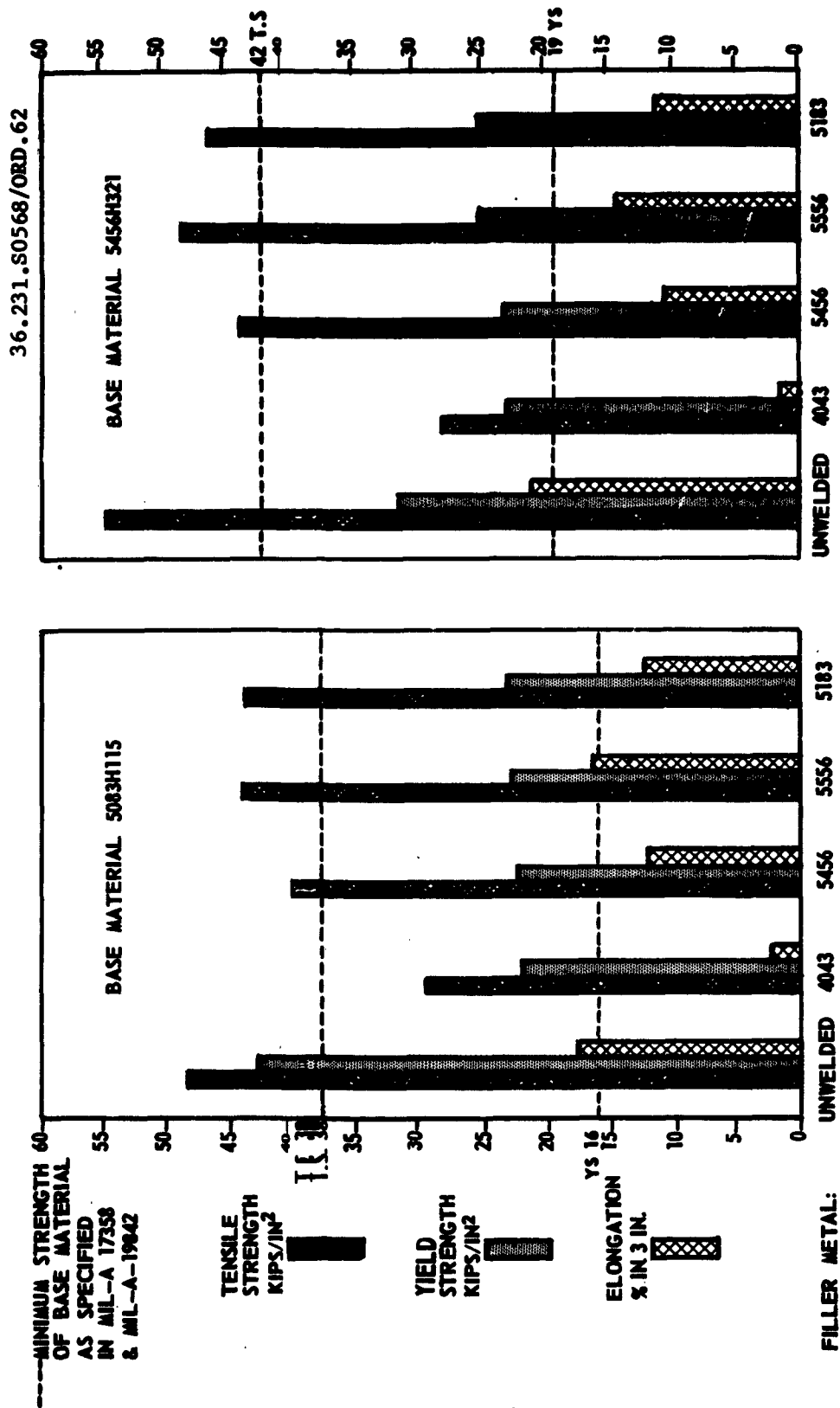


Figure 7. Strength of Butt Welds in Wrought Aluminum-Magnesium Alloys 5083-H115 and 5456-H321 of 1-1/4 in. thickness

It was noted that the joint efficiencies (Table II) were somewhat higher with base metal 5083 than with 5456. The average joint efficiencies of welds in both base metals made with 5556 and 5183 filler metals ranged from 86 to 91 percent. Filler metal 5456 provided joint efficiencies of 80 and 81 percent. The lowest joint efficiencies (52 to 61 percent) were experienced with 4043 filler metal.

The radiographic soundness ratings (Table II) suggest that the quality of the weld may have contributed, to some extent, to the ultimate strengths noted between certain combinations such as 5456/5556 and 5456/5183. The combination 5456/5183 with a rating "B" has a slightly lower tensile value than the 5456/5556 combination, which has a rating "A-B."

The yield strengths did not vary to any great degree in any of the welds, the lowest being the 22,100 psi for the 5083/4043 combination, and the highest being 25,900 for the 5456/5556 combination. The particularly low elongation values for welds made with 4043 filler material in either base alloy indicated much less ductile weldments than were produced with aluminum-magnesium filler alloys. In both base materials, welds made with 5556 filler wire exhibited the greatest elongation. Although the unwelded base alloy 5456 possessed slightly greater ductility than the unwelded 5083 alloy, the reverse was true for the ductilities of the welds in these alloys. The difference in this respect, however, did not appear to be significant.

Two tensile specimens after fracture are shown in Figures 8 and 9, as well as macrosamples cut from the same assemblies for base metal/filler metal combinations 5083/4043 and 5456/5556, respectively. It was noted that welds produced with the 4043 type filler alloy failed in a brittle manner with little, if any, visible necking of the specimens. Examination of the fracture revealed that failure occurred along the weld bead boundaries. In welds developed by aluminum-magnesium filler alloys (Figure 9) the mode of fracture was much the same as that which occurred in specimens representing the unwelded parent plate. The appearance of the fracture was the normal fibrous type, which is essentially characteristic of a "tough" break. Necking was also prominent.

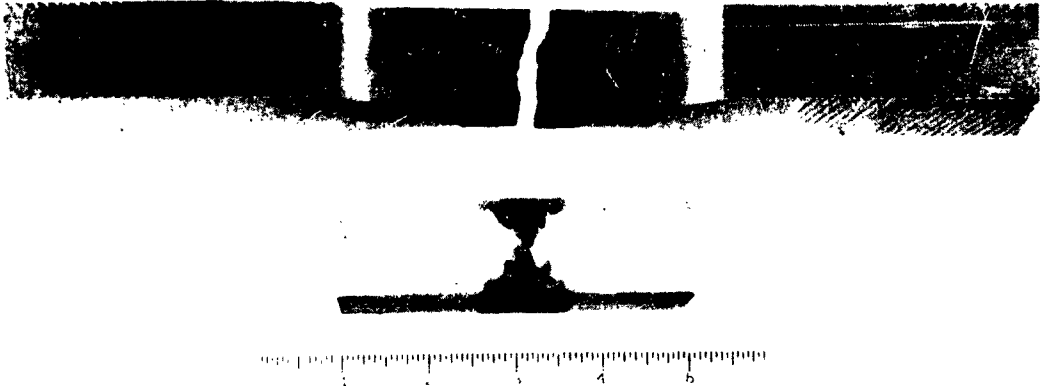


Figure 8. Tensile and macrospecimen of weldment:

Parent alloy - 5083-H115  
Filler alloy - 4043

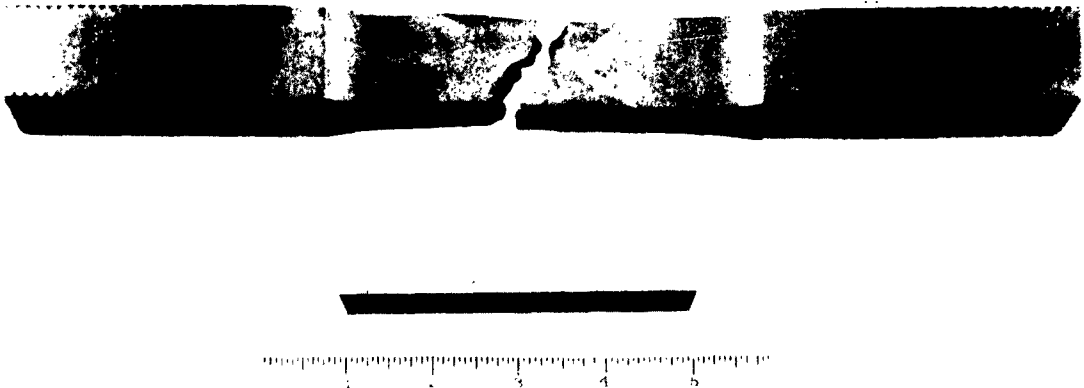


Figure 9. Tensile and macrospecimen of weldment:

Parent alloy - 5456-H321  
Filler metal - 5556

## CONCLUSIONS

The following conclusions may be drawn from the data in this report.

1. The use of 5556 and 5183 aluminum-magnesium alloys as filler material in welding 5083-H115 and 5456-H321, 1-1/4 inch plate, provides slightly higher transverse weld tensile strengths than the use of 5456 filler metal, and a marked increase in strength and ductility over that which was obtainable with the 4043 filler alloy.
2. Ultimate tensile strengths transverse to the weld were generally higher in 5456-H321 plate than in 5083-H115 plate, possibly reflecting, to some extent, the difference in the strength of these base materials.
3. A slightly higher joint efficiency resulted in welds of 5083-H115 than in corresponding welds of 5456-H321 for all filler metal/base metal combinations.
4. The filler metals 5183 and 5556 produced the highest joint efficiencies.
5. The greatest ductility experienced in both 5083-H115 and 5456-H321 weldments was obtained when the 5556 filler alloy was used.
6. For each filler metal, 5083-H115 weldments demonstrated slightly greater ductility than did 5456-H321 weldments.
7. The radiographic soundness of the welds probably affected the strength properties of the weld, although the degree of influence was not established.

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